Attenuation of Longitudinal Sound Waves in Potassium in an Oblique Magnetic Field*

M. Greene, A. Hoffman, A. Houghton,
R. Peverley, J. Quinn and G. Seidel
Department of Physics
Brown University

It has been suggested by Overhauser[1] that the alkali metals might possess spin density wave ground states. A possible experimental test of this hypothesis is the determination of the absorption edge for Doppler shifted cyclotron resonance[2,3] of acoustic waves in an applied magnetic field $\vec{B}$. Doppler shifted cyclotron resonance is possible when the condition

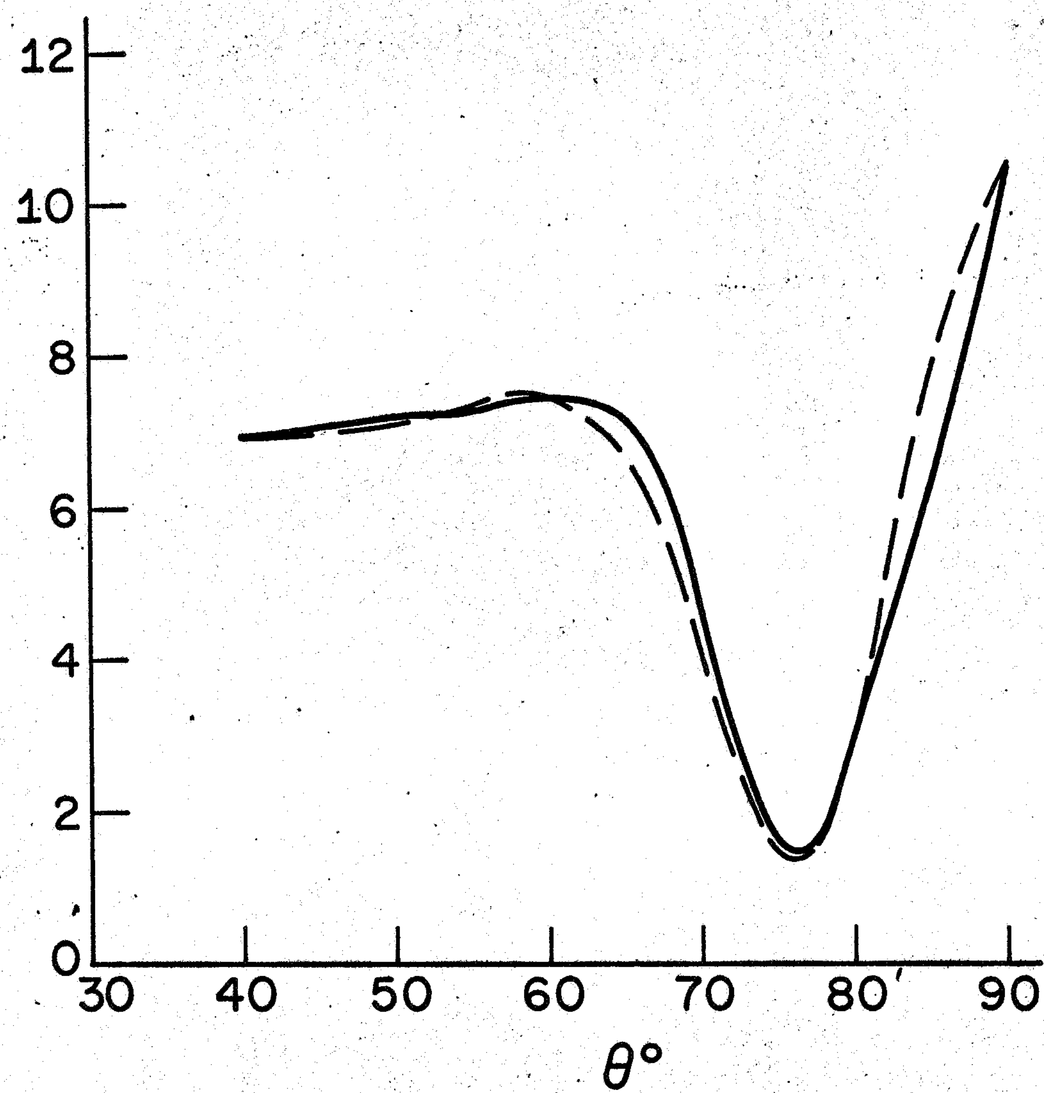
$$|\pm n|\,\omega_c \le |\vec{q}\cdot\vec{v}_M| \pm \omega \qquad (1)$$

is satisfied for n = 1, 2, ..., where ω and ω_c are the acoustic and cyclotron frequencies respectively; $\vec{q}$ is the wave vector of the sound wave and $\vec{v}_M$ the maximum electron velocity parallel to the dc magnetic field. If the spin density wave is oriented parallel to the dc field as proposed by Overhauser[1], the value of v_M in potassium is about 17% smaller for SDW state than v_F, its value for the free electron model. Thus by studying the position of the absorption edge, one can determine the value of v_M and test Overhauser's conjecture.

For transverse acoustic waves propagating parallel to $\vec{B}$, there is a selection rule that requires n = 1 in Eq. (1) while for longitudinal waves n must be zero in this situation. As one varies the direction of propagation with respect to the direction of $\vec{B}$, this selection rule is broken. There are some experimental difficulties in studying the propagation of shear waves (e.g. rotation of the plane of polarization), so we have investigated the attenuation of longitudinal waves propagating at oblique angles to the dc field. For propagation parallel to the magnetic field we expect the attenuation to be independent of field, while for propagation normal to $\vec{B}$ we should observe the standard geometric resonances. At intermediate angles we expect to see combinations of magneto-acoustic resonances and absorption edges due to Doppler shifted cyclotron resonance[4].

The experiments were performed on single crystals of potassium[5] at liquid helium temperature for acoustic frequencies ranging from 20 to 140 Mc/sec. The resistivity ratios of the samples were of the order of 7000 at 4.2°K, and they increased slightly by pumping on the helium. In figures 1 and 2 some of the experimental results are given and compared with theoretical estimates. Figure 1 is a plot of attenuation vs. the angle between $\vec{q}$ and $\vec{B}$ for a magnetic field corresponding to $(\omega_c/qv_F) = 0.4$. Figure 2 is a graph of attenuation vs. magnetic field at an angle of 70 degrees.

The theoretical curves displayed in these figures were computed from the conductivity tensor and attenuation given by Cohen, Harrison and Harrison[6]. The value of the parameter $q\ell$, where ℓ is the electron mean free path, was determined by fitting the theoretical and experimental curves of Figure 1 at angles of 90 and 75 degrees. It should be pointed out that the value of $q\ell$ obtained in this way was about 36% smaller than the value obtained from determining the frequency at which the ratio of zero field to the high field attenuation at 90 degrees equals unity. This discrepancy and the difference in the detailed shape of the curves near 90 degrees remain to be explained; however, the position of the minimum and general shape of the curves near the absorption edge are insensitive to the value of $q\ell$. For a SDW model we expect the absorption edge (i.e. the dramatic increase in attenuation at about 70 degrees) to be shifted to lower angle by about 5 degrees. The second Figure uses the value of $q\ell$ determined from Figure 1 to compare the magnetic field dependence of attenuation predicted by the free electron model with the experimental results for propagation at an angle of 70 degrees. The agreement between the free electron model and experiment appears to rule out the existence of a SDW state if it is aligned parallel to the magnetic field.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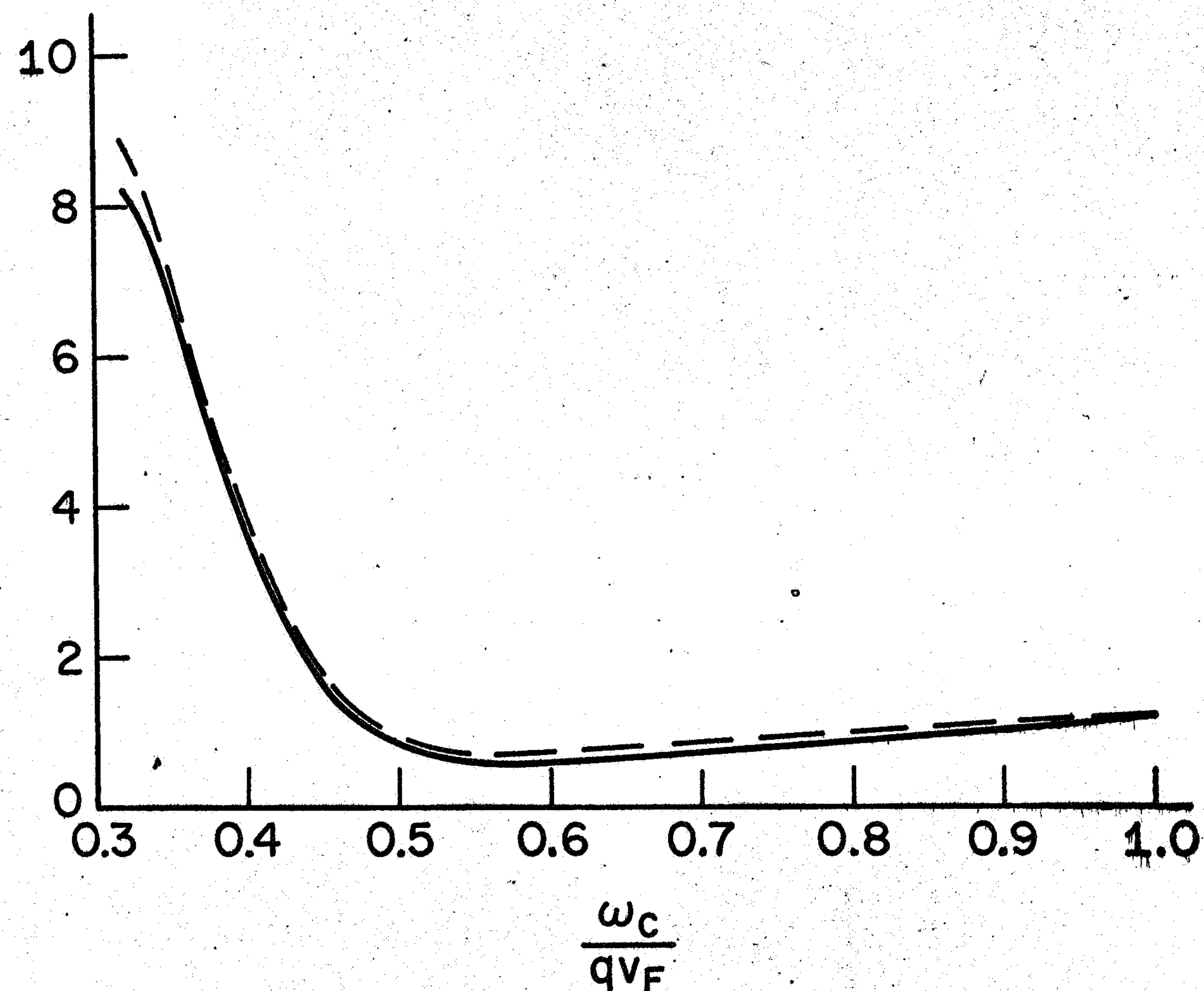
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$\frac{\omega_c}{qv_F}$

Footnotes and References

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1. A. W. Overhauser, Phys. Rev. Letters 13 (1964) 190.

2. T. Kjeldaas, Jr., Phys. Rev. 113 (1959) 1473.

3. R. C. Alig, J. J. Quinn and S. Rodriguez, Phys. Rev. Letters 14 (1965) 981.

4. This experimental arrangement has been suggested and studied experimentally in antimony by Eckstein and Eckstein; see S. Eckstein, Physics Letters 20 (1966) 142 and Y. Eckstein, Physics Letters 20 (1966) 144.

5. The potassium crystals used in this work were kindly supplied by Professor P. Meijer of Catholic University.

6. M. H. Cohen, M. J. Harrison and W. A. Harrison, Phys. Rev. 117 (1960) 937.

Figure Captions

Figure 1.

A graph of the attenuation (in arbitrary units) vs. angle for a fixed magnetic field. The value of B was chosen so that $\omega_c/qv_F = 0.4$. The solid curve is the experimental result for an acoustic frequency of 60 Mc, and the dashed curve is the prediction of the free electron model with $q\ell = 15$.

Figure 2.

A graph of attenuation (in arbitrary units) vs. ω_c/qv_F, which is proportional to magnetic field. The angle between $\vec{q}$ and the dc magnetic field is 70°. The frequency and mean free path are the same as in Fig. 1. The dashed and solid curves are theory and experiment respectively.

ABSTRACT

The absorption edge for Doppler shifted cyclotron resonance of longitudinal sound waves in potassium is found to agree with the prediction of the free electron model, demonstrating that the ground state of this material does not possess a spin density wave aligned parallel to the magnetic field.